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FARM DRAINAGE PUMPING PLANTS 1/

by

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The national importance of drainage in the conservation program is receiving increasing recognition. According to Soil Conservation Service preliminary estimates, farmers are cultivating about 60 million acres that should not be cultivated but should be retired for such uses as grazing and forestry. Most of this land is eroding and is too steep for successful cultivation. As these misuses of land are being corrected large additional acres of land will need to be drained and cultivated as well as developed by clearing and irrigation. As population increases there will be an increasing need for draining good land.

The drainage of lands is particularly important in the conservation program because drained lands are usually flat and not subject to serious erosion. Good conservation means shifting of row crops such as corn, cotton, and soybeans to flat non-erodible lands. Steeper lands subject to serious erosion can be used less intensively as other lands are available.

The program of soil conservation districts is encouraging proper methods of land drainage. These districts often furnish technical assistance in connection with land drainage by groups and individuals. Such drainage is often accomplished by use of pumps. Small farm-size pumps are becoming increasingly important in land drainage. They are no more complicated than tractor-drawn farm equipment. Another trend is toward larger pumping plants that have a greater capacity per acre and therefore help to avoid crop losses by securing drainage under conditions of high rainfall. This trend and the need for securing more efficient plants will result in enlarging or replacing many plants.

However, before a new drainage pumping plant is installed the feasibility of the project should be determined. The plant is one part of a complex and somewhat costly development. Such projects usually involve levees, drainage systems, land clearing and development, farm drains, and other farm-conservation structures and practices. Pumping and other costs should be compared with income from land drained to determine the justification of the project.

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Farm Drainage Pumping Plants

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Conditions for Pumping

Farm drainage pumping plants are being used in increasing numbers to provide drainage for land in which a gravity drainage outlet cannot be obtained readily. Land which is below or nearly level with nearby oceans, lakes, rivers, and streams affords opportunities for successful drainage by pumping. Land may be so flat or irregular in general topography that low areas may be drained more economically by pumping than by the construction of long, deep outlet drains. Pumps also provide controlled drainage of peat and muck soils and in some cases for sandy soils and tidal marshes.

In irrigated areas, pumping may be needed to lower the ground-water table that has risen to dangerous levels from overirrigation and seepage from canals and laterals. Such pumps may collect water from wells in water-bearing strata or from deep open or closed drains. Pumping may be the only practical kind of drainage for many areas. For other areas there may be a choice of pumping or of accepting an impaired drainage outlet during part of the year because of high stages of the outlet water levels.

The economic considerations are of primary importance in planning farm pumping plants. Frequently there is a choice of drainage methods such as drainage by gravity ditches extended a considerable distance or at considerable depth, or drainage by pumps. Other factors also need to be studied such as feasibility of obtaining right-of-way for outlets, constant attention of operation of pumping plants and the problems of interruption of service due to breakdowns, repairs and other causes.

Paper prepared for SCS state conservation engineer training meetings, May 1954.

Definitions of Terms Used

The following are the definitions of terms frequently used in planning farm drainage pumping plants:

Watershed Area
The area of land actually drained by the pumping plant. This is usually an area larger than the farm land drained and may include steeper lands having a high rate of runoff. It also includes areas in roads, ditches and levee right-of-way, etc.

Runoff
The water that flows or is removed from a watershed area. It is generally measured in average depth in inches over the area.

Drainage Coefficient
The capacity for stated conditions which a drainage pumping plant or other drainage facility should be designed. It is generally expressed in inches depth per 24 hours over the watershed area or in rate of flow per square mile or acre.

Acre-foot
The volume of water required to cover 1 acre 1 foot deep, equalling 43,560 cubic feet; it is often abbreviated A. F.

Acre-feet-feet
The product of the number of acre-feet pumped and the height (in feet) that the water is raised. The energy consumed in raising one acre-foot of water one foot is equivalent to 1.3728 horsepower-hours or 1.0237 kilowatt-hours. It is abbreviated A. F. F.

Centrifugal Pump
A pump in which water flows through an impeller and outward in a radial direction developing hydraulic pressure through the action of centrifugal force. According to the standards of the Hydraulic Institute centrifugal pumps with single inlet impellers usually have a specific speed below 4200. Double suction impellers usually have a specific speed below 6000.

Impeller
The moving rotor which has vanes or blades to force the water through the pump. A double suction impeller has two suction inlets, one on each side of the impeller. A closed impeller has side walls extending from the suction openings to the outer circumference of the vanes. The opem impeller has no side walls and vanes are attached to the hub. Some single suction impellers are semi-enclosed with one side wall.

Axial Flow or Propeller Pump
A pump of this type is called either, the "axial flow," "propeller" or "screw" pump. It develops its head by the propelling action of the impeller vane similar to the action of the ship propeller. This pump

has a single suction inlet in which the flow is in an axial direction and the discharge is likewise nearly axial. Pumps of this type usually have a specific speed above 9000.

Mixed Flow Pump
The pump in which the head is developed partially by centrifugal force and partially by the force of the vanes acting on the liquid. This type of pump ordinarily consists of a single suction impeller which directs the flow in an axial and radial direction into a volute type casing. Pumps of this type have a specific speed from 4200 to 9000.

Stage of Pump
A pump having one impeller is referred to as a single stage pump. A pump which has two or more impellers develops the hydraulic pressure and is referred to as a multi-stage pump.

Vertical Pump
A pump in which the pump shaft is vertical. This pump is called the suction type if the impeller is above normal operating water level of the suction bay. This is called a submerged type if the impeller is ordinarily submerged.

Rotation of Pumps
Designated as clockwise or counter-clockwise and determined as follows:

a. To determine the direction of rotation of a horizontal pump stand at the driving end and face the pump.

b. To determine the rotation of a vertical pump look down on the pump.

Wearing Rings
A removable ring inserted in the casing in which the impeller rotates with close tolerance is called a casing wearing ring. A removable ring attached to the impeller and which has a close tolerance is called an impeller wearing ring. When leakage becomes excessive removable wearing rings may be replaced.

Suction Limitations
The limitations on the suction lift is one of the most important factors affecting the operation of centrifugal pumps. If the suction lift is too high the pump capacity and efficiency is seriously reduced.

R. P. M.
The abbreviation for revolutions per minute, used in measuring the speed of the shaft of a pump, engine, or motor.

Specific Speed
See formula and definition, page 18 .

Total Head on Pump
The equivalent in feet of water of the total pressure the pump is acting against. It is equal to the static lift plus friction and other losses in the piping system. Such losses include the loss where the water enters the suction pipe, the friction losses through the suction and discharge pipes, losses due to trash or obstructions in the pipes, losses caused by air entering the discharge pipe where it is under vacuum, and the loss of "velocity head" at the end of the discharge pipe. See page 17 .

Static Lift
The difference of elevation between the water in the suction bay and the water in the discharge bay if the discharge pipe is submerged. If the discharge pipe is not submerged the static lift is the difference in elevation between the center line of the water in discharge pipe at the high point of discharge and the elevation of water in the suction bay.

G. P. M.
The abbreviation for gallons per minute, the unit commonly used for expressing the discharge of a pump.

H. P.
The abbreviation for horsepower, the rate of doing work equal to raising 33,000 pounds one foot in one minute.

Rated Horsepower
The commercial rating of the engine or motor as determined by the manufacturer; usually it is shown on the name plate of electric motors and oil engines. It is often abbreviated R. H. P.

Load on Engine or Motor
The ratio of the actual brake horsepower developed by an engine or motor to its rated horsepower.

Input Horsepower
The rate of work done in the cylinders of an engine or the energy supplied to electric motors. The input horsepower times the mechanical efficiency of the engine or motor equals the brake horsepower.

Brake Horsepower
The rate of work available at the shaft of the engine or motor. It is abbreviated B. H. P.

Mechanical Efficiency of Motor
The ratio of the brake horsepower delivered by the shaft of the engine or motor to the input horsepower developed in the engine cylinders or delivered to an electric motor.

Transmission Efficiency
The ratio of the horsepower delivered at the pump shaft to the brake horsepower delivered by the engine or motor. This ratio is a measure of the efficiency of belts, gears or other means of transmitting power from the engine to the pump.

Pump Efficiency
The ratio of power delivered by the pump, as measured by the total head on the pump and the amount of water pumped, to the energy supplied to the pump shaft. The pump efficiency is always greater than the over-all efficiency. See page 16 .

Over-all Efficiency
The ratio of the work represented by the quantity of water pumped and the static lift to the energy input to the engine or motor.

Horsepower Hours
The product of the hours operated by a unit and the power (I. H. P. or B. H. P.) of the engine or motor.

Kilowatt-hour
The common unit for measuring electrical energy; it is equivalent to 1.341 horsepower-hours. It is commonly abbreviated K. W. H.

Plant Factor
The ratio of the work actually performed in brake horsepower-hours by an engine or motor during a given time to the brake horsepower-hours it would perform if run continuously for the same time while developing the rated brake horsepower.

Construction Cost
The amount of money expended for the construction of the pumping plant, including general overhead costs.

Depreciation
The loss in value which occurs from the use, wear, or obsolescence of equipment during the period which the pumping plant is in service.

Cost of Depreciation
Various methods are used for estimating cost of depreciation. One is to divide the construction cost by the estimated life. This is a conservative method used where the facility is to be depreciated in a few years. This method may assume that a reserve

fund is built up year by year which would equal the cost of the plant when it is worn out. Interest on the reserve fund is often not considered. If a considerable investment is involved and the life of the plant is to extend over a long period of years consideration should of course be given to financing the investment to reduce the fixed charges of interest and depreciation. This may be accomplished by using the depreciation reserve year by year to reduce any indebtedness incurred for the original construction of the pumping plant. This reduces the average interest charges. Another method is to invest depreciation allowances and build up a sinking fund so that the sinking fund will equal the cost of the plant when it is worn out. This method of computation assumes that the annual cost of depreciation plus the compound interest will equal the cost of the plant at the end of the period of time which is the estimated life of the plant. It should be noted that the method of computing depreciation assumes considerable importance in the selection of permanent installations which would last from 20 to 30 years. The estimated cost of depreciation should be based on a realistic method of financing the pumping plant.

Fixed Charges

Fixed charges of a pumping plant must be accurately defined for preparing cost estimates on the plant. Fixed charges include costs of interest and depreciation on the plant. This item may or may not include taxes. Drainage districts and enterprises organized under state laws are usually exempt from state taxes. Individuals may pay taxes on a pumping plant. Fixed charges may also be defined to include rentals, fire, wind, explosion or other insurance and other fixed costs.

RELATION OF PUMPING PLANT TO GENERAL PLAN OF DRAINAGE

In pumped areas drainage works such as levees, interior ditches, tile drains, and channels to divert hill streams should be planned by the designing engineer in order to obtain an integrated and economical plan of drainage. The diversion of hill streams is generally advisable even at considerable expense in order to reduce the costs of pumping and of maintaining the drainage ditches. Where the lands lie well above low-water stages of the outlet, gravity drainage sometimes can be obtained. Where gravity drainage could be obtained only for occasional short intervals it may be more economical to pump all the drainage than to install a sluiceway or similar structure.

Location of Pumping Plants

The location of the pumping plant is determined largely by the topography of the area and the ditch system. It is desirable to install all the pumping equipment at one location if possible to obtain lowest construction and maintenance costs. When an old pumping plant is being replaced, it is usually impracticable to change the location of the plant. When other conditions do not control, the best location may be determined by pumping lifts, suction bay storage, and foundation conditions.

Foundation Conditions—Soil Borings

Good foundation soils are not only desirable to minimize construction costs but as a safety factor during flood conditions. Some plants have been destroyed by levee breaks at the pumping plant during floods.

The existence of quicksand or other unstable material at the site may greatly increase construction costs and affect design. Adequate information on foundation conditions should be obtained by means of soil borings.

Storage at Suction Bay

It is desirable to provide for storage near the pumping plant if feasible. Storage in the suction bay is advantageous for several reasons. Where a substantial amount of storage is available, reduction in size of the pumping plant may be permissible. The fluctuations of the suction bay are reduced in amount, thereby providing more constant operating conditions. A large storage makes it possible to reduce night operations and consequently may result in decreased labor costs. In cases where advantageous

rates for electric power are available through "off peak" pumping a large storage is a distinct advantage. It permits storage of water during day hours and enables a reduction in penalties for peak-hour pumping.

Where the topography permits, it is often desirable to leave low sloughs, lakes, or ponds unreclaimed in order to provide storage.

Design of Open Ditches and Tile Lines

The design of open ditches and tile lines is an essential feature in adequate planning for drainage pumping systems. Drains must conduct the water from the fields to the pumping plant and must also provide for storage of excess water druing heavy floods. The runoff capacity provided by open ditches is determined on the basis of experience in the area in which the plants are located. Runoff curves for adequate drainage, often referred to as "drainage coefficient" have been used successfully by the Soil Conservation Service in designing drains for more than a decade and have provided a basis for adequate drainage systems. These curves are applicable in the formula for estimating maximum runoff, given on page 11. Information on drainage coefficients can usually be obtained through soil conservation districts. For truck crops and steep land higher drainage coefficients are used in accordance with local practice.

It is desirable to deepen and enlarge the outlet ditch considerable distance from the pumping plant to provide a suction bay which will provide a supply of water to operate the pump during periods of low flow. It is desirable to avoid too frequent starting and stopping of the pump.

DETERMINATION OF STATIC LIFTS

All available data relating to the stages of the discharge and suction bays should be studied to determine the maximum, minimum, and average static lifts of the pumps. The pump manufacturer needs these data in order to supply equipment that will operate efficiently at all lifts and be adequate in capacity at the maximum lift. The importance of the variations in lift has not always been recognized. The discussion under this section applies especially if the discharge pipe is submerged. If the discharge pipe discharges at atmospheric pressure the differences in the static lift are due chiefly to fluctuations in the stages of the suction bay. The static lifts usually can be determined best after the ditch system has been designed. The desirable maximum operating level, or optimum stage at the suction bay, ordinarily, is the level that will give drainage to the lowest important areas of cultivated land. The optimum stage may vary with

season of year and with weather conditions. This stage will ordinarily be 4 to 7 feet lower in elevation than the elevation of important areas of land requiring drainage.

MAXIMUM LIFT

The maximum lift should be taken as the difference between the maximum stage of the discharge bay and the optimum stage of the suction bay if the outlet pipe is submerged. If the outlet pipe is not submerged the center line of the high point of the discharge pipe should be used instead of the maximum stage of the discharge bay. The maximum lift must be determined accurately, because if estimated too low the capacity of the plant is likely to be inadequate during floods. The maximum lift may usually be determined from maximum recorded flood stages at nearby gages.

The annual publication of the United States Weather Bureau "Daily River Stages," gives the maximum, minimum, and daily gage heights for the river gages of the principal rivers of the United States. The maximum stage of the discharge bay along a river covered by records may readily be determined by plotting a profile of flood stages along the river or by interpolation of flood elevations between gaging stations.

Stream or lake gages are also maintained by the United States Geological Survey, the Corps of Engineers, United States Army, and by other Federal and State agencies.

The maximum lift for plant design sometimes may be decreased to the extent of the rise of the suction bay which necessarily occurs during floods. It is usually impracticable to prevent flooding of some low-lying areas during severe storms.

Study of operating conditions during flood periods has shown the importance of designing a plant to pump its full capacity at the maximum lift. Full-capacity pumping frequently must be begun several days before the maximum river stage occurs and be continued until the flood crest has passed. A considerable period of inundation might cause greater crop losses in a single year than the entire cost of an adequate pumping plant.

MINIMUM LIFT

For plants having a submerged discharge pipe the minimum lift should be assumed to be the difference between minimum stage of

discharge bay and optimum stage of suction bay, based on mean monthly figures. For plants requiring much pumping at low lifts it is important to have at least one pumping unit that will operate efficiently near the minimum lift.

In many instances the minimum elevation of the discharge bay is above the minimum river or lake or other controlling stage. This is the case when the bay is a considerable distance from the river or where obstructions intervene. The advantages of enlarging and deepening such an outlet channel to secure a lower average lift should be considered.

AVERAGE LIFT

The average lift for use in designing a drainage pumping plant may be determined from the average monthly lifts weighted according to the amounts of runoff pumped in the respective months. For plants which will operate a high percent of time pump efficiency is especially important. In such cases it becomes desirable to estimate average lift and provide for efficient pumping at that lift.

DETERMINATION OF RUNOFF TO BE PUMPED

The runoff to be pumped often includes, in addition to the normal flow from drains, a large amount of seepage from nearby hill lands and from bordering rivers or creeks.

The rate of surface runoff depends on the amount, intensity, and distribution of rainfall and other precipitation, storage, the size and shape of watershed, the ground slopes, the vegetal cover, and the character of soil. The rate of seepage from hill lands is often an important factor in pumping requirements and its amount depends upon the local conditions. The rate of seepage from adjacent bodies of water depends especially upon the difference in elevation of the water inside and outside the drainage district, the extent of water-bearing gravel and sand under the district, and the length and location of drains touching the water-bearing strata. Because of the large number of influencing factors, the amounts and rates of runoff to be pumped can best be estimated from comparisons with similar areas from which the drainage runoff pumped has been measured.

For the design of a drainage pumping plant careful estimates should be made of (1) the average yearly runoff, (2) the seasonal distribution of that runoff, and (3) the maximum

daily runoff. The yearly runoff must be known in order to estimate the annual cost of pumping and determine the feasibility of the project. The seasonal distribution of the runoff as well as the lifts must be known in order to design an efficient pumping plant. The maximum daily runoff determines the total capacity of the plant and is considered one of the most important determinations to be made in designing any pumping plant. This determination should be made locally based on conditions encountered.

FORMULA FOR MAXIMUM PLANT CAPACITY

A formula for computing the required capacity of drainage pumping plants was developed. When the runoff from rainfall exceeds the capacity of the pumping plant, the excess runoff goes into storage. This storage includes ground-water storage caused by a rise in the ground-water table, ditch storage, and surface storage in sloughs and low areas. Storage may occur at locations away from the pumping plant and not be reflected in a large or rapid rise of the suction bay. Evaporation and transpiration losses of water help to dry up a drainage district, especially during the growing season and are then important factors to consider.

Crop losses result when the pumping plant capacity is inadequate due to flooding of low areas or to frequent rises in the ground-water table. It is economical to provide a larger pumping capacity to protect land or crops of high value.

The pumping capacity includes runoff from gravity plus seepage which occurs in pumping districts.

These relationships may be expressed as follows:

$$\text{Maximum plant capacity} = \text{coefficient} \left[\begin{matrix}\text{gravity}\\ \text{drainage}\\ \text{runoff}\end{matrix} + \begin{matrix}\text{seepage}\\ \text{runoff}\end{matrix} \right]$$

The formula for maximum plant capacity may thus be modified in general terms as follows:

$$C = K_1 \left[G + (K_2 \times r) \right] \tag{1}$$

in which

C = plant capacity at maximum lift, in inches runoff per 24 hours.

K_1 = pumping-district coefficient, a ratio between drainage coefficient from land in a pumping district and drainage coefficient

of similar land receiving gravity drainage. Where land and crop values are high this coefficient may approach unity if it is desired to give all land the same degree of protection as it would receive for gravity drains. For small areas, such as a few hundred acres, it would approach unity except for storage. However, due to the storage factor, as discussed above, this ratio may ordinarily be reduced. For the Mississippi valley plants studied the coefficient K_1 was found to be about 0.33 for 1950 conditions. For farm pumping plants draining not over 200-300 acres, this coefficient may be considered as unity unless a measurable part of the maximum 24-hour runoff will be stored in sloughs, low areas, or in permeable soils such as peat, muck and sandy land.

G = drainage coefficient or drainage modulus for land having gravity drainage expressed in inches per 24 hours. This would be the capacity for which open drains would be designed, in accordance with the usual Soil Conservation Service recommendations for gravity drainage systems.

$K_2 \times r$ is a term which gives the seepage flow to be pumped for maximum runoff conditions expressed in inches per 24 hours. Maximum seepage was found to be related to average annual runoff to be pumped.

K_2 is a coefficient (ratio) to convert annual runoff to maximum seepage in inches per 24 hours. This coefficient would be about 0.023 for conditions in the upper Mississippi Valley.

r is average annual runoff to be pumped. For the investigation this was found to vary as follows: 5 to 12 inches per year for districts having considerable gravity drainage; 13 to 16 inches per year for non-seeped districts pumping all runoff; and 16 to 35 inches per year for heavily seeped districts.

K_2 and r can be determined only by a study of operating pumping plants in the locality.

The coefficients K_2 and r were determined for upper Mississippi Valley plants which averaged 15,000 acres of watershed area with a range in size from 6,230 acres to 52,000 acres.

The original investigations as modified by later experience would indicate the formula for maximum plant capacity for upper Mississippi Valley pumping plants to be as follows:

$$C = K_1 (G + .023 r) \qquad (2)$$

Where C = maximum plant capacity in inches per 24 hours; K_1, see explanation above. G = drainage coefficient for similar gravity drainage systems (C curve); r = annual runoff to be pumped in inches.

This formula was arrived at by empirical methods and is believed to represent a relationship in which observed data seem to be reasonably well related. It is a rational approach to breaking the runoff into two parts, gravity flow and seepage. Coefficients may be arrived at for other areas if sufficient data are available.

PLANT CAPACITY FOR LOUISIANA AND TEXAS

A considerable area of coastal marsh in Louisiana and Texas has been developed by drainage pumping. Early investigations of the drainage pumping plants in southern Louisiana were made by Charles W. Okey, drainage engineer, United States Department of Agriculture. The pumping capacity of the districts ranged from 0.93 inches per 24 hours to 2.55 inches per 24 hours. Reservoir capacity ranged from 0.28 inch per 24 hours to 2.20 inches per 24 hours. The combined capacity of the pumping plant and reservoir ranged from 1.29 to 3.45 inches per 24 hours. An analysis of the combined 24-hour pumping and reservoir capacities of the 25 districts covered showed that : 2 districts had from 1.00 to 1.49 inches; 5 districts had from 1.50 to 1.99 inches; 11 districts from 2.00 to 2.49 inches; 5 districts from 2.50 to 2.99 inches; and 2 districts from 3.00 to 3.49 inches per 24 hours. It should be noted that the data given in figure indicate that rains in excess of 6 inches in 24 hours may be expected once in 5 years.

The investigations of Anderson and Moore,[1] Soil Conservation Service, revealed that many of the original pumping plants having a capacity of about 1.5 inches per 24 hours or less were found to be inadequate. As a result of the examination by Anderson and Moore a runoff capacity of 3 inches per 24 hours, including pumping capacity and reservoir capacity, is now recommended. Storage is computed as that available in areas below the elevation of the lowest cultivated land. It includes storage available on marsh lands, in borrow pits, and slough. Ditch storage is often so small it can be neglected. For example, if a reservoir storage in a pumping district is 1 inch per 24 hours the pumping plant should be designed for not less than 2 inches per 24 hours. The combined capacity figure of 3 inches per 24 hours applies to land used principally for growing sugar cane. A greater capacity may be advisable for special or truck crops or where local property requires better protection. The recommended combined pumping and reservoir capacities may be

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[1] Anderson, T. C., and Moore, R. B., Unpublished Report, 1947.

reduced to 2 inches per 24 hours if the principal crop is rice or pasture. These rates apply to the area along the Gulf Coast of Louisiana and Texas south of a line from Natchez, Miss., to Natchitoches, La., then roughly parallel to the Gulf Coast to Victoria, Tex. North of this line and in Arkansas the total pumping capacity and storage capacities may be reduced by 20 percent to 2.4 inches per 24 hours for land used principally for cotton and to 1.6 inches per 24 hours for rice or pasture land. These recommendations are based on drainage of flat areas less than 3,000 acres.

In the examinations of Anderson and Moore it was found that many of the original plants failed from lack of pumping capacity. Many of the successful districts originally started out with smaller capacity but have increased them.

PLANT CAPACITY FOR FLORIDA

For open-ditch drainage of the Everglades the engineering board of review developed and recommended the following formula:

$$Q = \frac{69.1}{M} + 9.6$$

in which Q = runoff in cubic feet per second per square mile of drainage area, and M = drainage area in square miles.

This formula was used by L. A. Jones in preparing plans for water control of organic soils of the region. The formula provides 1-inch runoff depth per 24 hours from 16 square miles, three-fourths-inch from 43 square miles, and one-half inch from 322 square miles. As in other areas this formula is based on the assumption that the land will be overflowed for short periods of time following excessive rainfall. It is not intended to provide complete flood control.

B. S. Clayton, drainage engineer, Soil Conservation Service, in conducting long-time investigations of conditions in the Florida Everglades found that many of the northern Everglades pumping districts serve from 5 to 13 sections of land. Most of these pumping plants were designed to remove 1-inch runoff per 24 hours. Much of this land is used to grow sugar cane. Experience over a 20-year period indicates that the 1-inch rate is generally ample for growing sugar cane on the organic soil of the area.

It was found, however, that truck crops suffered losses where the capacity was only 1-inch per 24 hours. As a result of Clayton's investigations the following rates are recommended for land used for growing truck crops in organic soils: 3.0 inches for 1 section of land or less, 2.0 inches for 2 to 3 sections of land, 1.4 inches for 4 to 9 sections of land, and 1.0 inch for 10 to 16 sections of land.

These rates approximate those given by the runoff formula quoted above. A long pumping record at the Everglades experiment station, Belle Glade, Fla., indicated that a runoff of 3 inches per 24 hours was required to protect crops on areas of 1 square mile or less.

In recent years a considerable number of pumping plants have been installed to serve land used for growing pasture grass for cattle. These pumping plants usually drain from 2 to 4 sections of land. A runoff of from 1 to 2 inches was commonly provided for these grazing areas and appeared to be adequate.

SELECTION OF PUMPS

Centrifugal, mixed flow, and axial flow or propeller pumps are commonly used for drainage pumping.

Centrifugal pumps may be designed for efficient pumping against total heads exceeding approximately 12 feet. Mixed-flow pumps can operate efficiently at heads from 6 to 26 feet. The axial-flow or propeller-type pump is ordinarily limited to pumping against heads less than 12 feet.

PUMP EFFICIENCIES

Usually, drainage pumps may be furnished with the maximum efficiency something over 80 percent. A well-designed pump should have an efficiency above 70 percent over a wide range of operating lifts.

Important pump installations are usually supplied by a manufacturer based on specifications prepared by the purchaser. The purchaser specifies the requirements at maximum and other operating lifts. Generally, the manufacturer supplies a set of characteristic curves to the purchaser similar to those shown. Such curves show pump capacity related to head, speed, efficiency, and brake-horsepower requirements. Most manufacturers base such curves on factory tests of the pump furnished or on the tests of a geometrically similar pump.

Pump efficiency is computed by the following formula:

$$e = \frac{g.p.m. \times H_t}{BHP \times 3960 \times e_t}$$

where

e = pump efficiency
g.p.m. = gallons per minute
H_t = total head on pump
b.h.p. = brake horsepower output of motor or engine
e_t = transmission efficiency of belt or gear connecting engine or motor and pump.

For units where the pump is directly connected to motor or engine e_t is 100 percent, and B.H.P. is equal to the horsepower input into pump shaft. For belt connected units e_t varies from 95 to 98 percent and only a small loss of power results.

TOTAL HEAD

The total head on the pump is equal to the total energy in the water at the discharge flange minus the total energy at the suction flange of the pump. It is expressed by the formula

$$H_t=(H_d+\frac{V_d^2}{2g}+d_1)-(H_s+\frac{V_s^2}{2g}+d_2)$$

in which H_t is the net total head, in feet of water.

H_d is the discharge pressure head, in feet of water, measured near the discharge flange of the pump. It is positive if the pipe is under pressure, and negative if under vacuum, at the point of measurement.

V_d is the average velocity, in feet per second, in the pipe at the point where H_d is measured;

d_1 is the elevation of the gage measuring H_d in feet above some reference plane. It is positive or negative depending upon whether the gage is above or below the reference plane.

H_s is the suction pressure head, measured near the suction flange of the pump. It is nearly always negative, since the suction pipe is usually under vacuum.

V_s is the average velocity in the pipe at the point where H_s is measured.

d_2 is the elevation of the gage measuring H_s above the same reference plane from which d_1 is measured.

g is the acceleration due to gravity, used herein as 32.16 feet per second per second.

The expressions $\frac{V_d^2}{2g}$ and $\frac{V_s^2}{2g}$ are the velocity heads in the discharge and suction pipes, respectively.

The total head is equal to the static lift plus all losses in suction and discharge pipes.

SPECIFIC SPEED AND MAXIMUM SUCTION LIFT

The specific speed of an impeller is a valuable index of the type of pump and is important in determining the maximum suction lift. The specific speed of an impeler is the revolution per minute to which a geometrically similar impeller would run if it were of such size as to discharge 1 gallon per minute against 1-foot head.

The formula for specific speed is as follows:

$$N_s = \frac{\sqrt{g.p.m.} \times r.p.m.}{H_t^{3/4}}$$

Where N_s=specific speed, g.p.m. is gallons per minute, r.p.m. is revolutions per minute, H_t is total head for a single stage pump which is used in drainage plants.

Excessive speed with too high a suction lift often results in serious trouble from vibration noise, pitting, and cavitation. A pump with a low specific speed will operate safely with a greater suction lift than one of a higher speed. If the suction lift is fairly high (over 15 feet) it is especially necessary to give particular consideration to the pump design. Usually this requires a slower speed and a larger and more expensive pump. If the suction lift is low a smaller and cheaper pump may be used.

The Hydraulic Institute, of which leading pump manufacturers are members, has adopted standards which cover upper limits of specific speed with respect to capacity, speed, head, and suction lift. Some impellers have been severely pitted by cavitation. This was no doubt influenced by the high specific speed for the suction lift. It is important for plant designers to keep the suction lift as low as possible and in all cases avoid exceeding limits specified by the manufacturer.

CENTRIFUGAL PUMPS

The double-suction volute centrifugal pump was used widely in early drainage plants. At the present time, efficiencies of 80 to 85 percent are guaranteed and obtained on centrifugal pumps at heads above 18 feet. Typical characteristic curves are shown in figure 5 . The Francis-type impeller, with curved vanes, is particularly efficient for drainage pumping.

Centrifugal pumps have a long life and are dependable. They usually have a greater capacity than the same size screw or mixed-flow pumps, especially against the higher heads.

AXIAL FLOW OR PROPELLER PUMP

The axial flow or propeller pump is especially adapted for low-head pumping. This type is also called a screw pump. The impeller has several blades, somewhat similar to those of a ship propeller, set on the shaft at angles determined according to the head and speed. The direction of flow through the pump does not change as in a centrifugal pump. A spiral motion of the water results from the screw action but may be corrected by diffusion vanes. The type has been used extensively in Louisiana, Florida and the upper Mississippi Valley especially for farm pumping plants.

The propeller pump operates at high efficiencies against heads less than 10 feet. One of its disadvantages is that the discharge falls rapidly at heads above 15 feet. The H.P. tends to rise at higher heads so adequate power must be provided to drive the pump.

This type pump can be built so the flow can be reversed if pumping is needed for both irrigation and drainage. This is quite an advantage for some locations, such as Florida, where supplemental irrigation is desirable and for organic soils.

An interesting development of the propeller-type pump has been its manufacture out of a welded steel pipe with a propeller similar to a boat propeller attached to a shaft and welded inside the pipe casing (fig. 8). This type of pump has been made at some local machine shops. A considerable number have been sold to farmers for drainage of small tracts less than 200 acres. The advantage of this type of pump is its low cost. The disadvantage is that little is known about the performance characteristics and efficiency of individual pumps. Some have been built with such light outside casings that blocks of wood passing the screen have broken through the casing. In other cases the annual cost of pumping with such units was so low that a higher efficiency would not have too much effect on annual savings.

MIXED-FLOW PUMPS

The mixed-flow pump also is particularly adapted for drainage pumping. It has an open vane, screw-type impeller, which combines the screw and centrifugal principles in building up the pressure head as shown in figure 4. It operates efficiently against somewhat higher heads than the true screw pump. With one change in speed the Hartwell mixed-flow pump operated at 70- to 80-percent efficiency at all heads from 6 1/2 to 26 feet, and the discharge did not decrease excessively at the higher heads (fig. 7). The open-type impeller of the mixed-flow pump facilitates the passage of trash.

VERTICAL SUBMERGED PUMPS

Submerged single-suction pumps have been used chiefly in smaller plants for the drainage of individual farms or small areas. (figs. 9 and 10). Usually the motor or engine to drive the propeller is mounted at the head of the unit. Such pumps may be equipped with any type of impeller driven by a vertical shaft. One advantage is that a small building will satisfactorily house the motor and switchboard. Another advantage is the elimination of priming equipment, which makes them especially suitable for automatic operation. This is a very important advantage for the farm or smaller pumping plant. Many small plants would not be economical if they required constant attendance.

The greatest disadvantage of vertical types is the inaccessibility of the pump for cleaning. When this type is installed, provision should be made to clean the pumps by closing the suction bay, preferably by gate valves, and draining the pump pit with a small auxiliary pump; or by hoisting the unit above the water level, which is practicable with small pumps. The difficulty in cleaning this type of pump makes it especially desirable to provide effective screens.

SPEED ADJUSTMENT

Against high heads pumps of the types described are most efficient when operated at higher speeds than at lower heads. Prospective purchasers usually can obtain from the pump manufacturer characteristic curves for use in determining the different speeds of operation.

Most electric farm installations do not provide for speed adjustments. Internal combustion engines should be slowed down at low lifts.

Transmission Equipment

Direct-connected pumping units are much preferred to belt- or gear-connected units because power losses in transmission are eliminated, the costs of purchase and maintenance of transmission equipment are saved, and less flood space is occupied by each unit.

Leather belts, V-shaped belts and gears are used in farm pumping plants for transmission of power from the engine or motor to the pump. Proper alignment of pump and engine is important, and where obtained the efficiency of transmission equipment will probably average 95 to 98 percent.

Size and Number of Pumps

Most farm pumping plants require only one pumping unit. For larger areas and high value crops it is an advantage to have two or more units in a plant so that a breakdown of one will not stop all pumping. This is especially true for a farm that is entirely dependent on the plant for drainage. Experience has shown that in a plant with two units that a desirable range of pumping rates is obtained by having one pump half the capacity of the other unit.

As a general rule the most economical size of pump will discharge the water at a velocity of 8 to 10 feet per second against the maximum head.

COMPUTING PUMP SIZES AND HYDRAULIC LOSSES IN PIPES

Table 1 shows pump or pipe discharges for various sizes from 6 to 30 inches. The column, acre inches per 24 hours, enables a ready check of the acreage served if the drainage coefficient is known. The velocities are given for various discharges and sizes. Pumps may be tentatively selected on a basis of about 7 to 8 feet per second for preliminary design and to obtain quotations from manufacturers. The size may be modified after manufacturer's performance curves are obtained.

The friction losses in suction and discharge pipes may be computed from King's Handbook of Hydraulics. The loss of head per 100 feet in suction and discharge pipes may be estimated from Figure 14 or Table 1. The loss in discharge pipes in Figure 14 was determined from the Scobey formula with $K_s = 0.51$, applicable to pipe three-sixteenths to seven-sixteenths inch thick, having all seams held by rivets with projecting heads, and pipes approximately 15 years old conducting non-aggressive waters. Some of the values are slightly different from the numerical values given in Table 1 which are based on Williams and Hazens formula for 10-year old pipes.

Entrance loss coefficients are as follows according to King's Handbook:

For inward project entrance	$K_e = .78$
For sharp cornered entrance	$K_e = 0.50$
For slightly rounded entrance	$K_e = 0.23$
For bell mouth entrance	$K_e = 0.04$

These values would be substituted in the Formula $H_e = K_e \frac{V^2}{2g}$, where H_e is head loss at entrance and K_e is coefficient of entrance loss. For small pumping units, a slightly rounded entrance with the entrance loss about 1/4 of the velocity head is usually obtained. The loss of head due to bends, enlargements and contractions may also be computed by coefficients given in King's Handbook of Hydraulics.

The velocity head loss, $\frac{V^2}{2g}$, is based on the velocity at the end of the discharge pipe and is usually one of the largest hydraulic losses in a well designed pump unit. The velocity head should not be confused with the entrance loss. Values of the velocity head are shown in Figure 14 and Table 1. Part of the velocity head may be recovered by expanding a submerged discharge pipe.

The discharge pipes of most small drainage pumps are 2 to 4 inches larger than the pump-flange connection. The increase in size of pipe should be accomplished by a uniformly expanding section at the pump flange.

The total head is equal to the static lift plus all hydraulic pipe losses plus the velocity head loss at the end of the discharge pipe.

POWER REQUIRED

The required capacity of the engine or motor may be determined by the formula

$$BHP = \frac{0.0002526 H_t Q}{e e_t}$$

in which,

BHP = brake horsepower required

H_t = total head on pump, in feet

Q = discharge in gallons per minute

e = efficiency of pump

e_t = efficiency of belt or other power transmission between engine and pump

When the power requirement has been determined, some adjustment in the speed and capacity of the pump usually is necessary to fit the load to a power unit of commercial size. Pump characteristic curves should be checked to determine adequacy of motor or engine for: Load at the shut-off point, the starting load, and load at total heads below the maximum. The power should be sufficient to operate satisfactorily under all operating conditions.

The required horsepower for various discharges for 10-foot total head and for combined pump and transmission efficiency of 70 per cent is shown in Table 1. This column enables an approximate check of horsepower computations.

AUTOMATIC OPERATION OF PLANT

Farm pumping plants may be made completely automatic if adequate electric power is available. Often electric plants are limited in size by the voltage available at the farm. A voltage of 220 single phase permits operation of 5- or $7\frac{1}{2}$-horsepower motors in some locations.

Automatic control may be obtained by a float which starts the motor when the water in the suction bay rises to a predetermined elevation. The pump then starts and gradually lowers the water and float. The water is pumped down to a level so the float trips a switch and cuts off the motor. Another device is to use an upper and lower electrode which will activate switches which start and stop the pump instead of a float. Information on layout and costs of electrical equipment including switches and floats may be obtained from several manufacturers of electrical equipment.

Special precautions must be exercised if the suction bay may freeze and prevent the float from operating properly. A vertical pipe filled with oil in which the float operates may be connected so as to reflect the stage of the suction bay. The float may operate in oil in below-freezing weather. Usually in very cold weather not much pumping is required and manual operation of a plant is satisfactory with the float or electrode removed from the water.

LAYOUT OF FARM PUMPING PLANTS

Farm installations have been characterized by efforts to save on first cost of the plant. Economy in first cost has been obtained by use of inexpensive foundations and a minimum of accessory equipment.

Many farm pumping units consist of a vertical submerged pump with free discharge similar in principle to Figure 9. An economical installation is the sloping pump set as shown in Plate 1A. Submerged pumps have generally been used for farm drainage pumping plants because no priming equipment is required and they are well adapted for automatic operation.

Where the discharge pipe is above high water in the discharge bay as in Figure 9, no flap gate is required. When the pump stops, there is no back-flow. Where the discharge pipe is submerged at low water as shown in Figure 10, an automatic flap gate at the end of the pipe should be provided to prevent back-flow through the pump. When the pump is started, the air escapes through an air escape valve. The vacuum breaker may be shut off when an attendant is at the plant and it is desired to operate the discharge pipe under vacuum. If automatic operation is desired, it is desirable to connect the vacuum breaker so as to admit air and avoid back-flow if the pump should stop when the flap gate is partially open. Figures 12 and 13 show other typical arrangements of pumping units.

Where the discharge line is submerged and the pump requires priming, a valve or gate must usually be installed in the discharge

line to facilitate priming and to prevent back-flow when the pump is stopped. A gate valve placed at the pump flange or a flap gate at the end of the pipe is used.

Typical conditions of priming during high-river stages are illustrated in Figure 12. If there is no effective gate or valve in the discharge line, operation of the vacuum pump will raise the water in the discharge pipe from B to C and at the same time raise the water in the suction pipe an equal distance from E to D. Then water from the discharge bay will commence to flow down through the pump, and often will cause a centrifugal pump to revolve backward. When this occurs it may be difficult or impossible to fully prime the pump before starting. If a centrifugal pump is not completely primed before starting, air is likely to be trapped around the impeller shaft, which reduces the pump discharge. On the other hand, a reasonably tight flap gate at A will keep the outside water from being drawn over the hump at C during priming. If there is an airtight valve at F, by closing it and the valve at G the pump can be primed more rapidly.

The propeller pump and the mixed-flow pump can be started before they are completely primed without danger of trapping air in the pump.

BUILDINGS AND FOUNDATIONS

A small substantial fire resistant building is a good investment for farm pumping plants. Electrical equipment needs to be protected. A small building also prevents damage by children or trespassers. In some cases where the pump is driven by a tractor or internal combustion engine, the buildings have been quite simple or pumps have been set in the open. (See Plates 1, 2 and 3 for examples.)

The foundations provided depend on the type of installation and soil conditions. For most mineral soils, piling are recommended for permanent installations. In some soils there may be sufficient bearing power to permit resting a concrete suction bay directly on the soil without piling. In some cases, the farmer is confronted with the necessity for pumping at the absolute minimum cost of installation. This may require setting a pump and engine on wood or steel beams and pumping from an open pit. In such cases, a propeller type pump resting at an angle on an embankment makes an economical installation. (See Plate 1A.)

Suction Bay

For permanent installations, it is desirable to build a concrete suction bay in which the pump may be submerged. It is absolutely essential that the pump or suction pipe be submerged an adequate depth in order for the pump to operate efficiently. In the preliminary plans, a submergence of three feet below normal low water pumping

level may be assumed for sea level pumping. Where the pump is 1,000 feet elevation above sea level, the minimum submergence should be increased to four feet. These figures should be modified on specific advice from the pump manufacturer based on requirements of the pump selected. Most manufacturers will provide specific recommendations as to submergence required.

The minimum clearance between the pump and side walls or suction pipe and side walls may be computed as 1.5 x pump size. For example, a 10-inch pump requires a minimum of 15-inch clearance from the side walls. This, of course, should be modified on recommendations of manufacturers. The minimum clearance between the suction edge of the pump and the floor of the intake bay may be designed equal to the pump size if manufacturers' recommendations do not specify otherwise. For example, a 10-inch pump requires a 10-inch clearance between the bottom of the pump or suction pipe and the floor of the suction bay.

Trash Screens

A good screen should be provided for each pumping plant to prevent trash from getting into a pump. These may be of small iron rods three-eights to one-half inch in diameter or of rectangular bars usually about one-fourth by $1\frac{1}{2}$ inches. The spacing between bars ranges from about $1\frac{1}{2}$ to 3 inches for small pumps. The area of the screen opening at average operating stages should be from 2 to 3 times the combined area of the suction pipe openings. If the screen area is too small, the water will head up unnecessarily, the static lift will be increased, and the pumps will lose their priming at a higher stage of the suction bay. The screens are conveniently made in sections 2 feet wide and supported by small channels or I-beams.

The most convenient location for the trash screen is across the front of the suction bay. The screens need substantial supports. Sloping the screen facilitates cleaning trash and debris.

Discharge Bay

In cases where discharge is somewhat high and soils are erosive, a constructed discharge bay may be required. In many plants the discharge pipe is extended far enough away from the pumping plant to avoid serious erosion. Many plants use a concrete flume in which the water may discharge.

EXAMPLES OF SMALL PLANTS

Several of the following plants have installed light propeller-type pumps to save on first cost. The discharge of many such units

drops materially when the life increases from 3 to 5 feet. Particular care is required in adapting such pumps to low-life installations.

1. A light drainage pump, operated by a gasoline engine, is shown in Plate 1, A. This unit is located in the Florida Everglades and pumps from the drainage ditch on the right to the outlet to the left. A V-belt pulley mounted on the head drives the pump shaft. The propeller is set under water and no priming is required. A screen attached to the suction prevents trash from entering. The engine is set on skids and could easily be moved.

2. Plate 2, A shows a reversible pump with a propeller-type blade having a capacity of 6,000 to 8,000 g.p.m. By turning one of two concentric cylinders, which form the pump barrel, 180°, the flow is reversed while the pump shaft continues to operate in the same direction. This unit is located in the Florida Everglades and is used for water control in the organiz soils. After heavy rains it is used for drainage; when the water table needs to be higher it serves for an irrigation unit. The static lift seldom exceeds 4 feet.

3. Figure 13 shows the cross section layout of a well-designed pumping plant for drainage of 46 acres of muck land. The pump is a vertical propeller-type rated at 1,270 g.p.m. at 9-foot total head when operating at 1,760 r.p.m. The plant has a runoff capacity of 1.16 inches per 24 hours from a 58-acre watershed. The pump is driven by a 5-horsepower repulsion induction motor mounted on the head and connected directly to the pump shaft. A view of the plant is shown in Plate 2,B. The Central La Peer Soil Conservation District furnished plans for this plant to the owner. Keith H. Beauchamp, Drainage Engineer, Soil Conservation Service, designed the plant.

4. Plate 2, C is a view of an electric-driven plant draining 155 acres, located in Lucas County, Ohio. The $7\frac{1}{2}$-horsepower motor is connected by three V-belts to the vertical submerged impeller-type pump. The pump capacity was estimated for design purposes at 2,600 g.p.m. at a low head, equivalent to a runoff capacity of 0.89 inch per 24 hours. An approximate rating was made when the water in the suction bay was at low stage and the pump discharge was estimated to be only half the designed capacity. However, as the suction bay rises it is probably that the 2,600 g.p.m. capacity is reached, indicating a great variation in capacity with a small difference in head. The pump discharged into a concrete-lined flume which ran into the outlet drain. No advantage is taken of the vacuum which would be created by a discharge pipe discharging below the water surface in the outlet channel. However, no vacuum pump or vacuum-breaking device is required and automatic operation of the plant is simplified. Automatic operation is secured by means of a float-controlled switch.

The soil, a silty clay, is drained by tile lines spaced at 50-foot intervals. A mile of open ditch serves as outlet for the tile lines.

The cost of the plant, which was completed in 1948, was $475 for pump house, foundation, and outlet flume. The owner did considerable work on the plant. The cost of the pump and motor was $394. The $7\frac{1}{2}$-horsepower motor is a 220-volt single phase. The 12-inch pump is a light-submerged propeller-type.

5. Plate 3,A shows a smaller plant countaining an 8-inch propeller-type pump located in Tuscola County, Michigan. The pump is belt-connected to a gasoline engine. The frame shed and pump rest on I-Beams across the ditch. This plant drains 120 acres.

6. Plate 3, B shows the top of a pump pit set underground which drains a low area of 25 acres through a tile located in Fulton County, Ohio. Before this old lake bed was pumped out it was wet; and about 5 acres could not be farmed. The pit contains a 2-inch sump pump, driven by a 2-horsepower motor. The cost of this pump and motor was about $300. The cost of concrete block sump pump was about $100 cash expenditure. This does not include the work of the owner who did most of the building. During the 11-month period, January to November 1948, the plant used 1,573 kilowatt-hours and the power cost was $53.70.

7. Plate 3,C shows an 8-inch locally manufactured propeller-type pump drawn by a 5-horsepower single-phase electric motor. An automatic float operates the motor switch. The pump cost $175 and the motor $175. The unit is supported on the concrete block head-wall over which the water is pumped to drain the farm lying upstream. This unit drains 120 acres.

Convenient Equivalents for Planning and Testing Pumping Plants

Volume

1 U. S. gallon = 231 cubic inches = .13368 cubic foot.

1 cubic foot = 1,728 cubic inches = 7.4805 U. S. gallons.

1 acre foot = 325,851 U. S. gallons = 43,560 cubic feet.

Hydraulics

1 U. S. gallon of water weighs 8.34 pounds.

1 cubic foot of water weighs 62.4 pounds.

1 cubic foot per second = 448.83 gallons per minute = 646,317 U. S. gallons per day = .9917 acre inch per hour (usually taken as unity) = 1.9835 acre feet per 24-hour day (usually taken as 2).

1 million gallons per day = 1.5472 C.F.S. = 3.07 acre feet per day.

1 inch runoff per 24 hours = 26.889 cubic feet per second per sq. mi. = .0420 cubic feet per second per acre = 18.857 gallons per minute per acre.

1 inch per hour = 1.0083 cubic feet per second per acre (usually taken as unity).

Pressure

1 foot of water at 39.1°F = 62.425 lbs. per sq. ft. = .4335 lbs. per sq. inch = .8826 inch of mercury at 30° F.

1 atmosphere at sea level = 33.90 feet of water.

1 pound on the sq. inch at 39.1°F = 2.307 ft. of water.

1 inch of mercury at 32°F = 1.133 feet of water = .49119 lb. per sq. inch.

Miscellaneous

1 year = 8,760 hours.

1 second-foot falling 8.81 feet = 1 horsepower.

Acceleration of gravity g = 32.16 ft. per second per second.

1 horsepower = 550 foot pounds per second = 33,000 foot pounds per minute = 746 watts.

1 kilowatt = 1.341 horsepower.

Table 1 Pump Discharge, Pipe Losses, Horsepower Required

Pump or pipe size in.	Gal. per min.	Acres inches per 24 hrs.	Pipe velocity ft. per sec.	Velocity head $\frac{V^2}{2g}$ ft.	Friction in ft. per 100 ft. of pipe	Horsepower required for 10 ft. total head. Pump and transmission efficiency = 70%
6	400	21.2	4.54	0.32	2.21	1.4
6	600	31.8	6.72	0.70	4.7	2.2
6	800	42.4	9.08	1.28	8.0	2.9
6	1,000	53.0	11.32	1.99	12.0	3.6
8	900	47.7	5.75	0.52	2.46	3.2
8	1,100	58.3	7.03	.77	3.51	4.0
8	1,300	68.9	8.32	1.07	4.72	4.7
8	1,500	79.5	9.60	1.43	6.27	5.4
10	1,200	63.6	4.91	.38	1.46	4.3
10	1,600	84.8	6.56	.67	2.35	5.8
10	2,000	106.1	8.10	1.02	3.65	7.2
10	2,400	127.3	9.73	1.5	5.04	8.7
12	2,000	106.1	5.60	.48	1.43	7.2
12	2,500	132.6	7.00	.77	2.28	9.0
12	3,000	159.1	8.40	1.10	3.15	10.8
12	3,500	185.6	9.80	1.49	4.10	12.6
14	2,000	106.1	4.20	.27	0.66	7.2
14	3,000	159.1	6.30	.61	1.47	10.8
14	4,000	212.1	8.40	1.09	2.47	14.4
14	5,000	265.2	10.50	1.71	3.92	18.0
16	3,600	190.9	5.74	.51	1.10	13.0
16	4,400	233.3	7.01	.76	1.58	15.9
16	5,200	275.8	8.29	1.06	2.16	18.8
16	6,000	318.2	9.56	1.42	2.60	21.6
18	4,500	238.6	5.70	.50	0.93	16.2
18	5,500	291.7	6.96	.75	1.32	19.8
18	6,500	344.7	8.22	1.05	1.82	23.4
18	8,000	424.2	10.02	1.56	2.65	28.9
20	5,000	265.2	5.13	.41	0.68	18.0
20	6,500	344.7	6.66	.69	1.06	23.4
20	8,000	424.2	8.17	1.03	1.63	28.9
20	10,000	530.3	10.40	1.68	2.53	36.1
24	8,000	424.2	5.68	.50	0.66	28.9
24	10,000	530.3	7.07	.78	0.98	36.1
24	12,000	636.4	8.50	1.12	1.40	43.3
24	14,000	742.4	9.95	1.54	1.87	50.5
30	12,000	636.4	5.44	0.46	0.47	43.3
30	16,000	848.5	7.36	.84	0.83	57.7
30	20,000	1061.	9.09	1.29	1.22	72.2
30	24,000	1273.	10.90	1.86	1.71	86.6